

## Technology Brief 1: LED Lighting

After lighting our homes, buildings, and streets for over 100 years, the incandescent light bulb created by Thomas Edison (1879) will soon become a relic of the past. Many countries have taken steps to phase it out and replace it with a much more energy efficient alternative: the **light emitting diode (LED)**.

### Light Sources

The three dominant sources of electric light are the incandescent, fluorescent, and LED light bulbs (Fig. TF1-1). We will examine each briefly.

#### Incandescent Light Bulb:

**Incandescence** is the emission of light from a hot object due to its temperature. By passing electric current through a thin tungsten filament, which basically is a resistor, the filament's temperature rises to a very high level, causing the filament to glow and emit visible light. The intensity and shape of the emitted spectrum depends on the filament's temperature. A typical example is shown by the green curve in Fig. TF1-2. The tungsten spectrum is similar in shape to that of sunlight (yellow curve in Fig. TF1-2), particularly in the blue and green parts of the spectrum (400–550 nm). Despite the relatively strong (compared with sunlight) yellow light emitted by incandescent sources, the quasi-white light they produce has a quality that the human eye finds rather comfortable. The incandescent light bulb is significantly less expensive to manufacture than the fluorescent and LED light bulbs, but it is far inferior with regard to energy efficacy and operational lifetime (see comparison section below). Of the energy supplied to an incandescent light bulb, only about 2% is converted into light, with the remainder wasted as heat! In fact, the incandescent light bulb is the weakest link in the overall conversion sequence from coal to light (Fig. TF1-3).

#### Fluorescent Light Bulb:

**Fluoresce** means to emit radiation in consequence to incident radiation of a shorter wavelength. By passing a stream of electrons between two electrodes at the ends of a tube [Fig. TF1-1(b)] containing mercury gas (or the noble gases



(a)

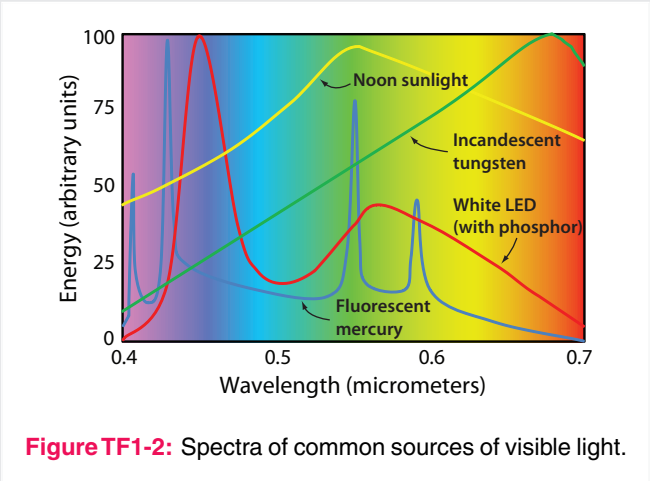


(b)



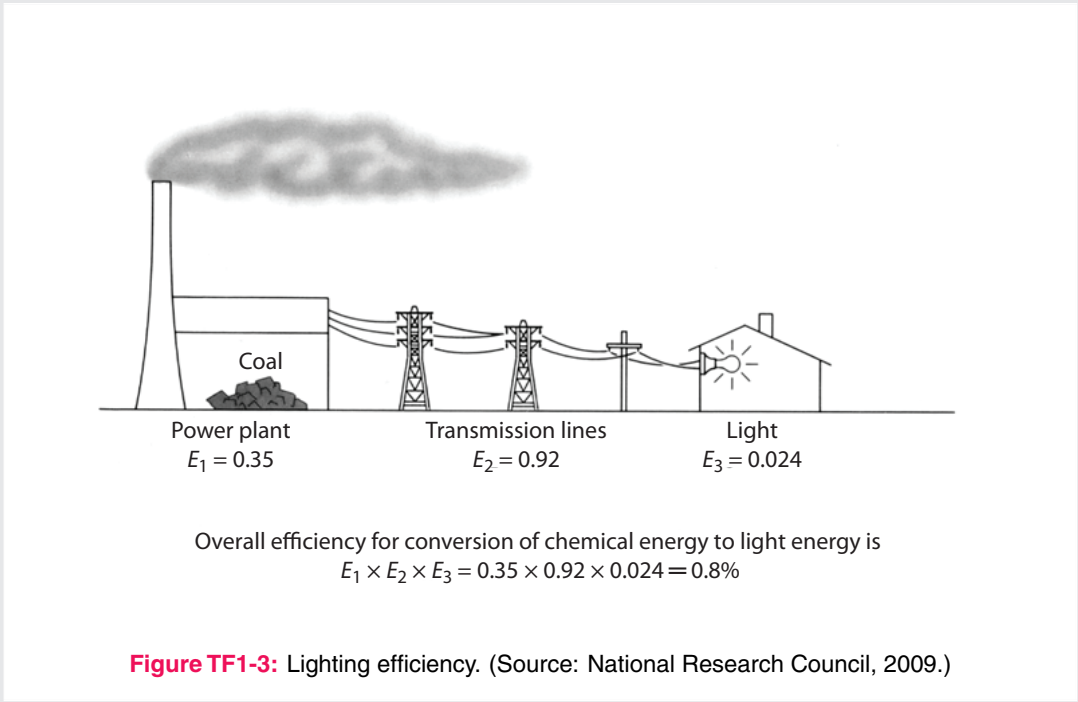
(c)

**Figure TF1-1:** (a) Incandescent light bulb; (b) fluorescent mercury vapor lamp; (c) white LED.

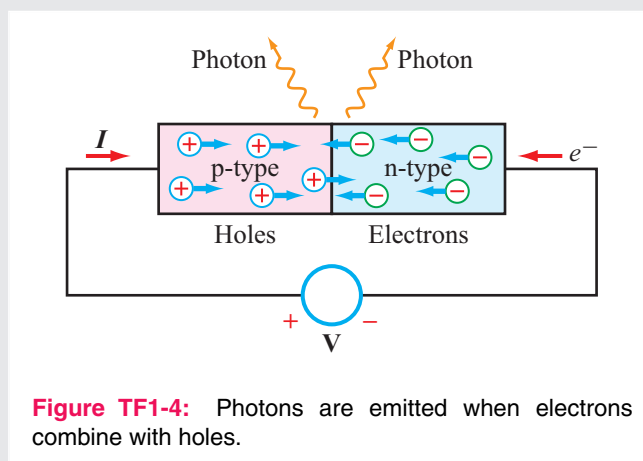


**Figure TF1-2:** Spectra of common sources of visible light.

neon, argon, and xenon) at very low pressure, the electrons collide with the mercury atoms, causing them to excite their own electrons to higher energy levels. When the excited electrons return to the ground state, they emit photons



**Figure TF1-3:** Lighting efficiency. (Source: National Research Council, 2009.)



**Figure TF1-4:** Photons are emitted when electrons combine with holes.

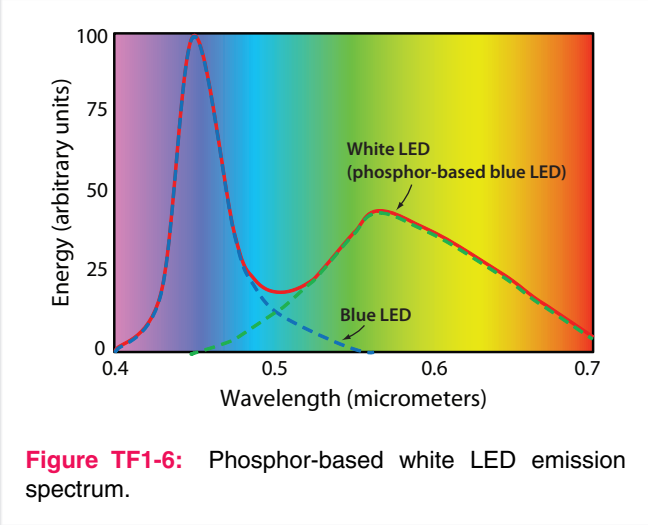
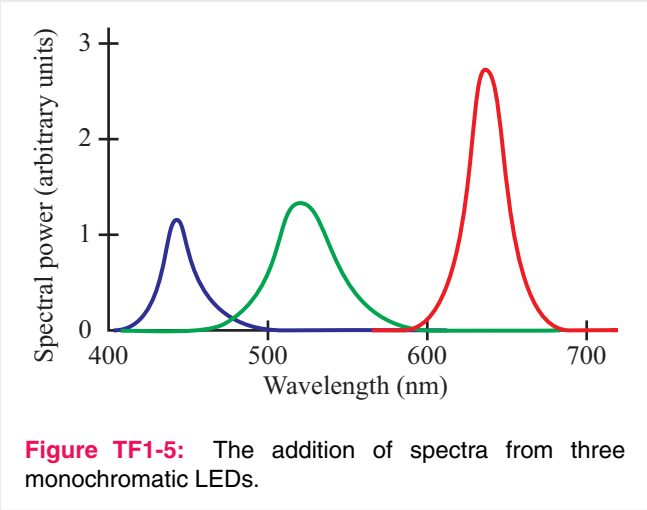
at specific wavelengths, mostly in the ultraviolet part of the spectrum. Consequently, the spectrum of a mercury lamp is concentrated into narrow lines, as shown by the blue curve in Fig. TF1-2. To broaden the mercury spectrum into one that resembles that of white light, the inside surface of the fluorescent light tube is coated with phosphor particles [such as yttrium aluminum garnet (YAG) doped with cerium]. The particles absorb the UV energy and then reradiate it as a broad spectrum extending from blue to red; hence the name *fluorescent*.

### Light Emitting Diode:

The LED contained inside the polymer jacket in Fig. TF1-1(c) is a p-n junction diode fabricated on a semiconductor chip. When a voltage is applied in a forward-biased direction across the diode (Fig. TF1-4), current flows through the junction and some of the streaming electrons are captured by positive charges (holes). Associated with each electron-hole recombining act is the release of energy in the form of a photon. The wavelength of the emitted photon depends on the diode's semiconductor material. The materials most commonly used are aluminum gallium arsenide (AlGaAs) to generate red light, indium gallium nitride (InGaN) to generate blue light, and aluminum gallium phosphide (AlGaP) to generate green light. In each case, the emitted energy is confined to a narrow spectral band.

Two basic techniques are available for generating white light with LEDs: (a) RGB and (b) blue/conversion. The RGB approach involves the use of three monochromatic LEDs whose primary colors (red, green, and blue) are mixed to generate an approximation of a white-light spectrum. An example is shown in Fig. TF1-5. The advantage of this approach is that the relative intensities of the three LEDs can be controlled independently, thereby making it possible to "tune" the shape of the overall spectrum so as to generate an esthetically pleasing color of "white." The major shortcoming of the RGB technique is cost; manufacturing three LEDs instead of just one.

With the blue LED/phosphor conversion technique, a blue LED is used with phosphor powder particles suspended in the epoxy resin that encapsulates it. The blue light emitted by the LED is absorbed by the phosphor particles and then reemitted as a broad spectrum (Fig. TF1-6). To generate high intensity light, several LEDs are clustered into a single enclosure.



Comparison

**Luminous efficacy** (LE) is a measure of how much light in lumens is produced by a light source for each watt of electricity consumed by it. Of the three types of light bulbs we discussed, the incandescent light bulb is by far the most inefficient and its useful lifespan is the shortest (Fig. TF1-7). For a typical household scenario, the 10-year cost, including electricity and replacement cost, is several times smaller for the LED than the alternatives.

| Parameter                              | Type of Light Bulb |             |            |            |
|--|--------------------|-------------|------------|------------|
|  | Incandescent       | Fluorescent | White LED  |            |
|  |                    |             | Circa 2010 | Circa 2025 |
| <b>Luminous Efficacy</b><br>(lumens/W) | ~12                | ~40         | ~70        | ~150       |
| <b>Useful Lifetime</b><br>(hours)      | ~1000              | ~20,000     | ~60,000    | ~100,000   |
| <b>Purchase Price</b>                  | ~\$1.50            | ~\$5        | ~\$10      | ~\$5       |
| <b>Estimated Cost over 10 Years</b>    | ~\$410             | ~\$110      | ~\$100     | ~\$40      |

**Figure TF1-7:** Even though the initial purchase price of a white LED is several times greater than that of the incandescent light bulb, the total 10-year cost of using the LED is only one-fourth of the incandescent's (in 2010), and expected to decrease to one-tenth by 2025.